Applications and Examples of Experiments with Mobile Phones and Smartphones in Physics Lessons

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Abstract

The contribution provides an overview of possible experiments with mobile phones in physics lessons. The focus of the article is therefore on the "mobile phone" as an experiment tool. Besides the use of mobile phones for documentation, experiments with mobile phones for analysing gravity acceleration and diffraction phenomena of infrared remote controls as well as experiments of the topic acoustics are discussed. This paper includes relevant examples of the project "N.E.T.–New Media Experimental Tools", which is located within the framework of situated learning theory based on the assumption that the authenticity of the media used in experiments has a positive learning impact on physics instruction. This assumption means that the learning success of the learners with regard to experimentation in physics lessons is greater, if a physical phenomenon is explored with experimental tools used every day (special focus on new media tools), albeit possibly for different purposes. The focus of this aspect of research is on the development of physical experiments using authentic media of this kind and on the impact of these media on learning and motivation.

Keywords

Mobile Phone Applications; Physics Education; Experimental Tools; Material-Aided Situated Learning Approach

Introduction

This article provides an overview of possible use and experiments with mobile phones[1] in physics lessons. The focus of the article is therefore on the "mobile phone" as an experiment tool–a topic that has been somewhat neglected in the field of educational research to date. Initial experiments using mobile phones have been described (Dengler, 2003; Falcão et al., 2009; Hammond & Assefa, 2007; Hare, 2011; Kuhn & Vogt, 2012a; Kuhn & Vogt, 2012b; Kuhn & Vogt, 2012c; Kuhn & Vogt, 2013a; Kuhn & Vogt, 2013b; Schwarz et al., 2013; Villa, 2009; Vogt et al., 2011; Vogt & Kuhn, accepted; a summary of currently published paper is presented in Kuhn, accepted)[2]. Mobile phones and smartphones can also be used to search for information, exchange data, communicate lesson contents, save lesson results and as cognitive tools: as unit converters or computer algebra systems, for example.

Mobile phones and smartphones are very suitable for serving as experimental tools, because they are usually equipped with a number of sensors. For example, most of the smartphones involve a microphone as well as acceleration and field strength sensors, a density of light sensor and a GPS receiver. As all the sensors can be read by appropriate software (apps), a large number of quantitative school experiments can be conducted with smartphones.[3]

This paper includes relevant examples of the project

[1] When referring to "mobile phones" in this context, we mean devices whose main function is to enable wireless and location-independent telephoning; in addition, they communicate with the telephone networks via wireless technology and integrate several simple software applications. "Smartphones", on the other hand, are mobile phones, which-alongside their function as wireless telephone-provide extensive additional computer functionality and connectivity in comparison to a traditional modern mobile phone and can be equipped with customized functions by the user by installing additional programs (so-called applications; short form: apps). As a result, a smartphone can be seen as a small transportable computer (PDA) with the additional functionality of a mobile phone.

[2] Some aspects of different experiments described in this paper are already published as short papers in a special column of another, relevant peer-review journal (see Kuhn & Vogt, 2012b). So for further information we refer to these short papers in some cases.

[3] For details concerning the application of smartphones acceleration sensor in physics lesson: see Vogt and Kuhn (submitted).

"N.E.T.–New Media Experimental Tools", which is located within the framework of situated learning theory based on the assumption that alongside the authenticity of the topic, the authenticity of the media used in experiments has a positive learning impact on physics instruction, thus material-aided situated learning. Hence, this aspect aims to provide a theoretical extension or specification of situated learning (aspects to date: thematic, episodic, social; Kuhn & Vogt, 2013a). In concrete terms, this assumption means that the cognitive and motivational learning success of the learners with regard to experimentation in physics lessons is greater, if a physical phenomenon is explored with experimental tools (in particular with "(every day) new media") used every day, albeit possibly for different purposes.

The focus of this aspect of research is, first, on the development of physical experiments using authentic media of this kind. In a second phase, the impact of these media on learning and motivation in everyday physics lessons with quasi-experimental control/test group research design have been investigated.

The Mobile Phone as a Means of Documentation

The mobile phone and its different functions can be used in various ways in physics lessons for documentation purposes. The dictation function, for example, enables the user to effortlessly record measurements, problems or improvement suggestions during the experiment, which can subsequently be integrated in the analysis of the experiment. The camera function, a standard component of almost every mobile phone nowadays, makes it possible to record the information that has been written on the board during the lesson in a time-saving manner (figure 1); in addition, photographs can also be made of experiment set-ups (figure 2). The student can copy the photograph of the board or experiment set-up to his/her exercise book at home after the lesson, or print it out and stick it in his/her exercise book. This approach is particularly useful for a single-period lesson, as it is frequently the case for the subject of physics. Experience has shown that very often in experiment-based lessons little or no time remains to record the lesson's results thoroughly.

The video function provides a further means of using the mobile phone as a means of documentation. It enables the recording of experiments with only minimal effort; and students can then watch the videos in order to analyse the experiment or make preparations (for example, in the next lesson or for verification) as many times as required.

The recorded video sequences (e.g. of a free-falling steel ball) can be analysed using appropriate software, demonstrating that the mobile phone is not only used as a means of documentation, but also as an experiment tool in physics classrooms. Further possibilities for using the mobile phone as an experiment tool are described in the following.

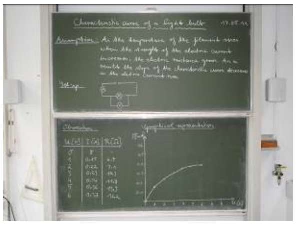

FIG. 1 RECORDING RESULTS WITH A PHOTOGRAPH OF THE BOARD USING THE INTEGRATED CAMERA

FIG. 2 PHOTOGRAPH OF EXPERIMENT SET-UP

Mobile Phones and Smartphones as Experimental Tools

Production of an Acoustic Beat

In order to produce an acoustic beat, two mobile phones, both equipped with an MP3 function, are required to generate tones. A tone with a constant frequency is stored on each of the mobile phones before the experiment[4], whereby the frequencies of the two tones should only differ by several hertz. The small difference in frequencies ensures that the beat, which results from the interference of the two tones, can also be heard with the auditory senses (the beat frequency, i.e. the number of changes in volume per time, depends on the difference between the frequencies of the two initial tones). In order to conduct the experiment, the two mobile phones have to be placed at a short distance from each other and then play the recorded tones with the MP3 function.

In order to analyse the acoustic beat quantitatively (beat frequency, frequency of interference), the signal can be captured using a microphone and connected to the line-in of a sound card (figure 3). The analysis is executed with suitable audio analysis software, e.g. Audacity [5] or Cool Edit Pro [6]. An example of an

[4] The tones can be generated by appropriate software (e.g. with the Software "Audacity" or "Test Tone Generator" (see: http://www.esseraudio.com/ [07/2013 and transferred via Bluetooth or a USB cable onto the mobile phones.

[5] Audacity(Freeware-Software for analyzing and handling tones). see: http://audacity.sourceforge.net/?lang=de[07/2013]]

experiment for the initial frequencies f_1 = 500 Hz and f_2 = 501 Hz is presented in figure 4.

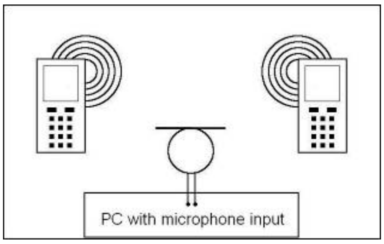

FIG. 3 EXPERIMENT SET-UP FOR THE PRODUCTION OF AN ACOUSTIC BEAT

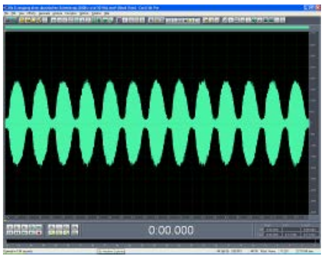

FIG. 4 OSCILLOGRAMME FOR AN ACOUSTIC BEAT PRODUCED BY TWO MOBILE PHONES PRESENTED USING COOL EDIT PRO AUDIO ANALYSIS SOFTWARE

In order to create a perfect beat, it is important to ensure that the mobile phones are set at the same playback volume and placed at an equal distance from the microphone. It is possible to verify that the volumes are the same beforehand by placing one of the mobile phones at a given distance from the microphone and measuring the sound it plays with the audio analysis software. Subsequently, the same measurement is made for the second mobile phone (figure 5); if necessary, its volume can be adapted according to that of the first mobile phone.

FIG. 5 QUANTITATIVE ANALYSIS OF AN ACOUSTIC BEAT USING A SMARTPHONE

Determination of the Acceleration of Gravity[7]

1) Set-up and Theoretical Background of the Experiment

If a free-falling mobile phone emits a tone[4] with a constant frequency f_0, the acceleration of gravity g can be determined very precisely on the basis of the resulting Doppler shift, which increases with the velocity of the fall. The basic experiment set-up can be seen in figure 6. Attention should be paid to positioning the microphone immediately next to the point of impact of the mobile phone; in addition, a cushion should be placed below the free-falling device in order to avoid damaging it.

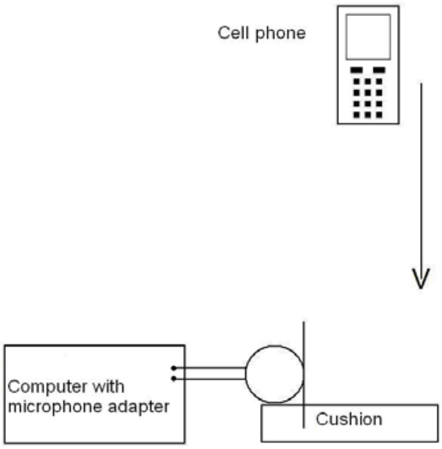

FIG. 6 EXPERIMENT SET-UP TO DETERMINE G; THE MICROPHONE CAN BE REPLACED BY A HEADSET OR ANOTHER MOBILE PHONE WITH A DICTATION FUNCTION, IF NECESSARY(VOGT ET AL., 2011)

It is even simpler to conduct the experiment with two smartphones installed with suitable tone generator apps (e.g. Audio Kit for iOS or FuncGen for Android); and the initial frequencies can be easily set and varied using the mobile phone. In addition, the analysis of the experiment can be performed by the smartphone, which is used as an oscilloscope (e.g. Oscope Lite for iOS) (figure 6).

The following equation applies to the resulting Doppler shift Δf, measured with a PC, with a good approximation given

$$\Delta f \approx f_0 \frac{v}{c} \tag{1}$$

(v velocity of fall of the mobile phone, c speed of sound in air) and with $v = g \cdot \Delta t$

$$\Delta f \approx f_0 \frac{g \cdot \Delta t}{c} \tag{2}$$

(Δt fall time).[7] If the frequency emitted remains constant, according to equation (2) Δf is approximately proportional to Δt and the quotient

$$\frac{f_0 \cdot g}{c} \tag{3}$$

can be considered the slope m of a straight line. After having recorded the measurements and determined the linear equation by means of a linear regression, the resulting slope can be used to calculate the acceleration of gravity. This is

[6] Cool Edit Pro (Shareware-Software for analyzing and handling tones; see: http://de.brothersoft.com/Cool-Edit-Pro-126679.html [07/2013]

[7] Further information: see Vogt et al. (2011).

performed with the following equation

$$g \approx \frac{m \cdot c}{f_0} \qquad (4)$$

2) *Analysis of the Experiment*

Figure 7 shows a measurement example for a mobile phone falling from a height of approx. 2.20 meters, emitting a 4 kHz tone[8]. The measured values underlying the presentation can be read from the graph or conveniently exported as a TXT data file. A graphic presentation of the time-dependent Doppler shift can be seen in figure 8; in accordance with theory (2), the change of frequency Δf is clearly proportional to the fall time Δt.

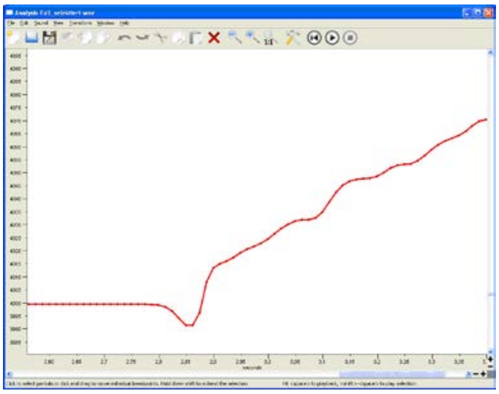

FIG. 7 THE PROGRESSION OF FREQUENCY RECORDED BY THE MICROPHONE, PRESENTED WITH SPEAR EVALUATION SOFTWARE[9] (VOGT ET AL., 2011)

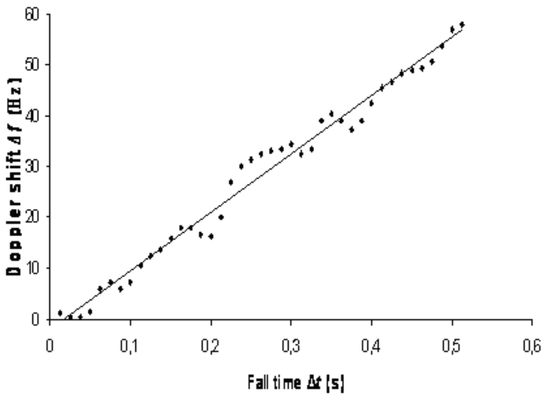

FIG. 8 RESULT OF THE LINEAR REGRESSION (VOGT ET AL., 2011)

The application of a linear regression results in a linear equation

$$\Delta f = 115 \frac{1}{s^2} \cdot \Delta t - 2.1\ \text{Hz}\,, \qquad (5)$$

with an adjusted coefficient of determination of 0.98 and a slope error of ± 2 s^{-2}. The application of the numerical values (4) results in a speed of sound in air of 344 ms^{-1} (at 20 °C) and gravitational acceleration as

$$g = (9.9 \pm 0.2)\frac{\text{m}}{\text{s}^2}\,. \qquad (6)$$

This shows that by applying the described procedure gravity can be determined with an acceptable degree of accuracy for school instruction. The literature value of 9.81 ms^{-2} is located within the error margin of the measurement.

An additional experiment to determine gravity, which makes use of the acceleration sensors integrated into smartphones, is described in Vogt and Kuhn (submitted).

The Mobile Phone Makes Infrared Radiation Visible[10]

The CCD chips used in digital cameras are also sensitive to electromagnetic waves in the near infrared range; and this property can be used to demonstrate interesting diffraction phenomena with simple everyday objects (Catelli et al., 2011; Kuhn & Vogt, 2012a; Williams, 2006). Alongside a mobile phone with a camera function, the objects required for the experiment are an infrared remote control, a diffraction grating with a suitable grating constant, e.g. 50 lines per millimetre (alternatively regular CDs or low-cost grating film can be used as reflection grating).

FIG. 9 EXPERIMENT SET-UP TO TAKE PHOTOGRAPHS OF THE DIFFRACTION IMAGES WITH A MOBILE PHONE

FIG. 10 DIFFRACTION IMAGE ON THE MOBILE PHONE DISPLAY (KUHN & VOGT, 2012A)

1) *Qualitative Experiments*

The experiment set-up is very simple (figure 9): The user shines the remote control onto the camera lens, whilst holding the optical grid directly in front of the lens.

[8] As the Doppler shift increases with the initial frequency ($\Delta f \sim f_0$), it makes sense to use the highest possible frequencies in order to facilitate the analysis with the evaluation software and reduce the relative error. The frequency response of the mobile phone speaker and the microphone used imposes a limit on the transmitted frequency, which is why, if data specifications are not available, it is necessary to conduct experiments beforehand to determine the ideal initial frequency for the experimental design.

[9] SPEAR (Freeware-Software for analyzing dynamical spectra). see: http://www.klingbeil.com/spear/ [07/2013]

[10] Further information: see Kuhn and Vogt (2012a)

The diffraction images can be photographed using the mobile phone (figure 10) and exported to a PC to be printed out and stuck in the pupils' exercise books. In figure 11 the image on the left was produced by an optical grid with 50 lines per millimetre and the image on the right by a grating film with 900 lines per millimetre.

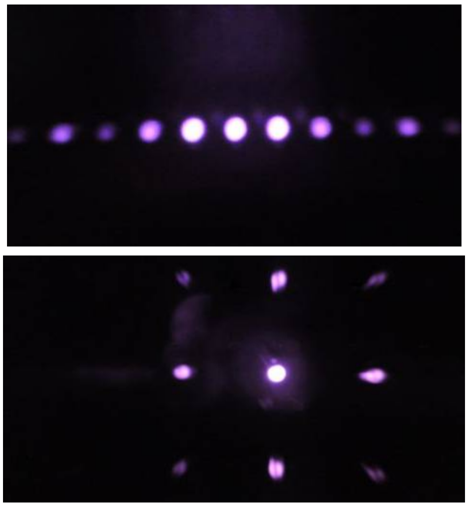

FIG. 11 DIFFRACTION IMAGES PRODUCED BY AN INFRARED REMOTE CONTROL AND OPTICAL GRIDS, PHOTOGRAPHED WITH A MOBILE PHONE CAMERA (KUHN & VOGT, 2012A)

2) *Quantitative experiments*

In order to determine the wavelength of the infrared radiation produced by a remote control, the experimental design is adjusted as in figure 9, introducing a measuring unit at the same height as the remote control for comparison. The grid and mobile phone must be adjusted so that the infrared radiation hits the grid and the interference image can be seen on the mobile phone display together with the measuring unit (figure 12). After having taken the photograph, the wavelength of the infrared radiation can be calculated with the help of geometric measurements from figure 13 and the formula for constructive interference as follows:

$$\sin\alpha = \frac{n \cdot \lambda}{g} \qquad (7)$$

(with n: side lobe; λ: wavelength; g: grating constant).

As the values s_n and l are difficult to determine, the geometric relationships of the experiment (figure 13) together with the theorem on intersecting lines result in:

$$\frac{s_n}{l} = \frac{s'_n}{l'} \qquad (8)$$

$\sin\alpha \approx \tan\alpha$ (for small α) results from(8):

$$\lambda = \frac{g \cdot s'_n}{n \cdot l'} \qquad (9)$$

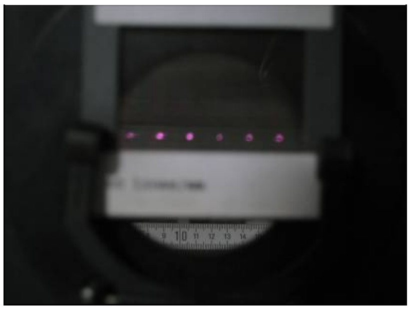

FIG. 12 DIFFRACTION IMAGE TO DETERMINE THE WAVELENGTH OF INFRARED RADIATION PRODUCED BY A REMOTE CONTROL (MEASURING UNIT AT THE BOTTOM RIGHT) (KUHN & VOGT, 2012A)

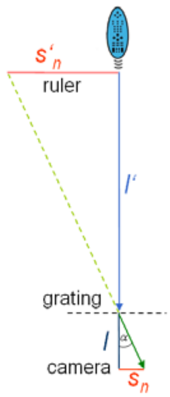

FIG. 13 GEOMETRY OF THE EXPERIMENT SET-UP

A measurement example performed for a remote control of the brand Benq (S/N: CT050606055) with an optical grid with the constants g = 1.25·10^{-5} m generates the following results: l' = 0.77 m, n = 2 and s'_2 = 11.5 cm. If the numerical values are inserted into (9), the wavelength of the infrared diode λ is calculated to be $\lambda \approx 930$ nm . The wavelength of this particular infrared diode could, unfortunately, not be ascertained; however, the value resulting from the experiment lies within the usual wavelength range for the infrared diodes used in remote controls (900 nm – 1200 nm).

Summary and Outlook

Alongside the well-known negative effects of mobile phones on everyday school life, modern mobile phones can be used to enhance physics instruction in school in many ways, e.g. in order to obtain information, to document experiments and to perform experiments when used as an experiment tool. In addition to several simple and obvious experiments (e.g. "infrared diffraction"–to produce diffraction images with the help of an infrared remote control), more complex experiments can also be conducted with mobile phones (e.g. experiments to determine gravity or experiments making use of the navigation function).

In order to increase the number of applications for mobile phones in physics instruction, on the one hand, additional new experiments should be developed; and this involves continually scanning the relevant databases of free commercial mobile phone applications (including, for example, the available apps for Smartphones). On the other hand, it is necessary to investigate the impact of this material-aided situated learning approach on learning and motivation and to evaluate which factor might make an used material of

an experiment more successful than another, or in other words: to evaluate a degree of material-aided situatedness. A first quasi-experimental pilot study indicates positive effects of this media on learning and self-efficacy (Kuhn & Vogt, accepted).

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Jochen Kuhn finished his university training to be a teacher for Physics and Mathematics in 1998 at the University of Koblenz-Landau, where he completed his PhD-Thesis in physics and physics education in 2002, too. In addition to graduation he had been working as high school teacher for over eight years before he became a scientific assistant at the physics education group of Prof. Dr. Andreas Müller (current position: Professor at the University of Geneva) at the University of Koblenz-Landau in 2008. After finishing his habilitation thesis there in 2009, he received different offers as full professor in Germany and Switzerland in 2011. Since 2012 he has been full professor and head of the Physics Education Group at the University of Kaiserslautern. His current research interests focus on using smartphones and tablet PC as experimental tools in physics education and in university courses, on teaching and learning in school labs as well as on context-based science education.

Patrik Vogt was born in 1978 in Germany. He got the university degree in Physics and Mathematics (junior high school teacher) at the University of Koblenz-Landau in 2003. During 2003-2010 he worked as a teacher in Herxheim and Kandel and received the Ph.D. degree in the field of physics education in 2010. After graduation, he was a postdoctoral fellow at the University of Koblenz-Landau and Kaiserslautern, then assistant professor at the University of Education Schwäbisch Gmünd. He is currently lecturer at the University of Education Freiburg and teaches physics and didactics of physics. His current research interests include context-based physics instruction, use of smartphones as an experimental tool and Very Low Frequency (VLF) radio phenomena.